PREPARATION OF AN ANECHOIC TANK FOR UNDERWATER SOUND MODELING STUDIES AND MEASUREMENT OF SURFACE IMAGE EFFECTS

ABDIEL R. YINGLING

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Abdiel R. Yingling, Jr.

Lieutenant, United States Navy

Submitted in partial fulfillment of
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ABSTRACT

Anechoic chambers have had many uses in acoustic investigations. However, most underwater work has been done using short pulses of acoustic energy to allow measurement of the acoustic variables prior to the beginning of the interference caused by reflections. It seems desirable to have an anechoic tank which will permit the use of a continuously emitting source, which permits both the use of somewhat simplier equipment, and the modeling of continuous wave, layered media propagation problems.

The construction of such a tank and the measurement of the surface image effect for such a continuous source is described.

The writer wishes to express his appreciation for the assistance and encouragement given him by Doctor Herman Medwin, Associate Professor of Physics, of the U. S. Naval Postgraduate School.

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TABLE OF SYMBOLS

Symbol	Meaning
A	Sound transmission anomaly. The transmission loss above the six decibels per distance doubled predicted by the inverse square law.
d	Depth of the sound source in centimeters.
h	Depth of the probe hydrophone in centimeters.
log	The logarithm to the base ten.
p	The sound pressure amplitude at any point.
R	The range in centimeters.
R'	The Lloyd critical range. It is equal to $\frac{4hd}{\lambda}$
sin	The trigonometric sine of an angle.
λ	The wavelength of a sound wave in centimeters.
π	3.1416

1. Introduction.

Anechoic chambers have been employed in investigations of acoustic phenomena in many ways. In underwater work, however, pulses of energy have generally been used instead of a continuous source in an anechoic tank.

Some underwater applications, such as acoustic minesweeping require continuous sources of sound.

Previous studies of this nature, notably that of Weinstein [1] were carried out in an anechoicly lined pond. This technique was used to study sound propagation in a two-layered medium with an infinite bottom layer.

With the increasing knowledge of impedances of various liquids, such as those listed by Del Grosso and Smura [2], it is possible to use multi-layered systems for tank modeling of layered media.

It was considered desirable, therefore, to have a small anechoic tank in which such underwater modeling studies could be carried out, and to verify the theoretical surface image effects close to the sound source.

2. Basic Theory.

The basic theory of an anechoic chamber is simple and well known. The chamber is lined with wedges of a sound absorbent material whose acoustic impedance is about equal to the acoustic impedance of the medium in the chamber. As the sound impinges on the wedges it meets an ever increasing resistive impedance while traveling down the space between the wedge edges. This absorbes acoustic energy and minimizes reflections and standing waves.

Reference (3) gives the solution for the wave equation for a sound source in a two-layered fluid continuum based on several assumptions. These assumptions are that both fluids are ideal, the pressure is the same in both fluids, and the particle displacement is the same in both fluids at the interface. The range is assumed to be very much greater than either the probe or source depth. The final assumption is that the surface reflected wave can be considered as a second source, directly above the first, the same distance from the interface, of the same strength but of opposite phase.

For a point source whose radiated field is

$$p = \frac{P}{R} e^{j(\omega t - Kr)}$$

the sound pressure amplitude due to the source and image, at any range is shown to be equal to

$$2 \frac{P}{R} \sin 2\pi \frac{hd}{R\lambda}$$

If the inverse square law for intensity were followed the maximum amplitude would be proportional to the reciprocal of the range. The transmission anomaly, that is, the loss in decibels above that of the inverse square law is given by

$$A = -20 \log \left[2 \sin 2\pi \frac{hd}{R\lambda} \right]$$

In the expression for the amplitude, it is readily seen that the amplitude vanishes for values of the argument of the sine term that are integral multiples of π. It is also seen that the amplitude will be a maximum for values of the argument that are integral multiples of $\frac{\pi}{2}$.

This alternate maxima and minima sequence is known as the Lloyd mirror effect, or the surface image effect. The range of the last such relative maxima is called the Lloyd critical range, and is equal to $\frac{4hd}{\lambda}$.

At large ranges the sine term may be replaced by the series expansion for the sine. The amplitude becomes

$$\text{Amplitude} = \frac{2P}{R}\left[\frac{2\pi hd}{\lambda R} - \frac{1}{6}\left(\frac{2\pi hd}{\lambda R}\right)^3 + \frac{1}{120}\left(\frac{2\pi hd}{\lambda R}\right)^5 - \ldots\right]$$

By neglecting the terms of second order and higher, the amplitude can be seen to be proportional to $\frac{4\pi hd}{\lambda R^2}$. It is readily seen that, for any given source and probe depth, and wavelength, there is a range beyond which the amplitude decreases as the inverse square of the range, and the intensity decreases as the inverse fourth power, or 12 decibels per distance doubled. This range is about eight times the Lloyd critical range. The anomaly beyond this point is constant at six decibels per distance doubled.

If the surface does not reflect perfectly, this development must be modified. However, perfect reflection is assumed throughout this paper.

3. Equipment.

The electronic equipment used consisted of an audio oscillator, a power amplifier, a cathode ray oscilloscope, and two voltmeters, all of standard types. The arrangement of the equipment is shown in Figure 1.

The probe used was a barium titanate cylinder 1/8 inch in diameter, and 1/8 inch in length, and having a wall thickness of .032 inch. This probe was made by previous students.

The sound sources were made of barium titanate as described in Appendix I, and sketched in Figure 2.

A tank six feet long, four feet wide,and two and one half feet high was available and was used. The anechoic liner was constructed of semi-porous concrete and sawdust blocks, sold under the trade name of "Insulkrete". A sketch of one of these blocks is shown in Figure 3.

As the water in the tank aged, a thin, hard, brittle scum developed on the surface. During the course of the data taking it was noticed that an accumulation of this scum caused a standing wave. When the scum was physically removed the standing wave disappeared.

4. Procedure.

A layer of insulkrete blocks was laid around the edge of the bottom of the tank, with the wedge edges horizontal and pointing toward the center of the tank. A second layer of blocks was placed on top of the first, but with the wedge edges vertical. The space remaining in the center of the tank bottom was then filled with blocks standing on end with the wedge edges pointing up and parallel to the long dimension of the tank. The blocks were fitted as tightly as possible. Successive layers were then laid around the edges of the tank until they reached the top (5 layers in all). The wedge edges were left horizontal on the sides of the tank, and were alternately vertical and horizontal on the ends. The tank was then filled with water and allowed to stand until the blocks were throughly soaked and had released all entraped air.

The probe was immersed and the overall ambient noise level was measured. The source was immersed, with the oscillator on but with the gain turned down and the noise level rose 20 decibels. This was taken as an indication that there was some electric or electromagnetic coupling between the source and the probe. The acoustic radiation was physically blocked by inserting a three-inch layer of styrofoam between the source and the probe, to indicate the relative levels of acoustic signal and electromagnetic signal. At a distance of 30 cm. a signal to noise ratio of 12 decibels was the maximum that could be obtained.

In attempting to obtain a higher signal to noise ratio by brute force driving of the source, the barium titanate cylinder was depolarized, cracked, and consequently ruined.

The second sound source was then constructed, using a barium titanate sphere. This source was insulated with an epoxy plastic resin spray in

an effort to reduce the coupling between the source and the probe. Using this source there was no noticeable coupling, and a signal to noise ratio of 30 decibels was obtained. The background noise was random.

Readings of sound pressure level at various ranges were then taken for various source and probe depths at a frequency of 15 kilocycles.

5. Results.

The results are presented graphically in Figures 4 and 5. Two cases are shown. Figure 4 is for a source and probe depth of ten cm., giving a critical range of 40 cm. Figure 5 is for a source and probe depth of four cm., giving a critical range of 6.4 cm. These two cases were used to have one case where the critical range was about one-half the working length of the tank in order to obtain better accuracy in measuring the alternate maxima and minima, and to have a second case with a short critical range, in order to have a relatively long region beyond the critical range.

In both figures only the anomaly is plotted, that is the six decibels per distance doubled is subtracted out of the data as taken. In Figure 4 the displacement of the peaks is probably due to the fact that the range is not very much greater than the source and probe depth as assumed in the development. In Figure 5, the best six decibels per distance doubled line is plotted. The data is in good agreement with this line at ranges greater than about eight times the critical range or 50 cm.

At ranges much greater than the critical range, there is little evidence of standing waves greater than decibels and the tank is considered to be anechoic at 15 kilocycles.

6. Recommendations.

It is recommended that further studies be carried out to determine the effect of adding a bottom layer to the tank, and modeling an open ocean situation.

BIBLIOGRAPHY

1. Marvin S. Weinstein, Short Range Propagation of Sound in Shallow Water, NavOrd Report 4373, 18 Sept 1956.

2. V. A. Del Grosso and E. J. Smura, Naval Research Laboratory Report 4191, 18 Sept 1953.

3. Research Analysis Group, Committee on Underseas Warfare, National Research Council, Principles of Underwater Sound, Div. 6, Vol. 7, NDRC Summary Technical Report.

APPENDIX I

CONSTRUCTION OF THE SOUND SOURCES

For the first source a barium titanate cylinder two cm. long, two cm. in diameter, and having a wall thickness of two mm. was used. The cylinder walls were painted inside and outside with silver paint. The silver was then bonded to the walls by heating it to red heat.

The ends of the cylinder were ground slightly to insure that there was no electrical contact between the inner and outer walls. Leads were then soldered to the walls. The cylinder was then heated in an oil bath to 120 degrees Centigrade and allowed to cool with a D. C. voltage of 3750 volts applied across the silvered surfaces. A High Voltage Power Source, Model HA-51, manufactured by the NJE Corporation, was used as the voltage source. For ideal polarization, 4750 volts should have been used to conform to the accepted value of 60,000 volts per inch for the optimum polarization of barium titanate. However, 3750 volts was the highest voltage that could be used without arcing.

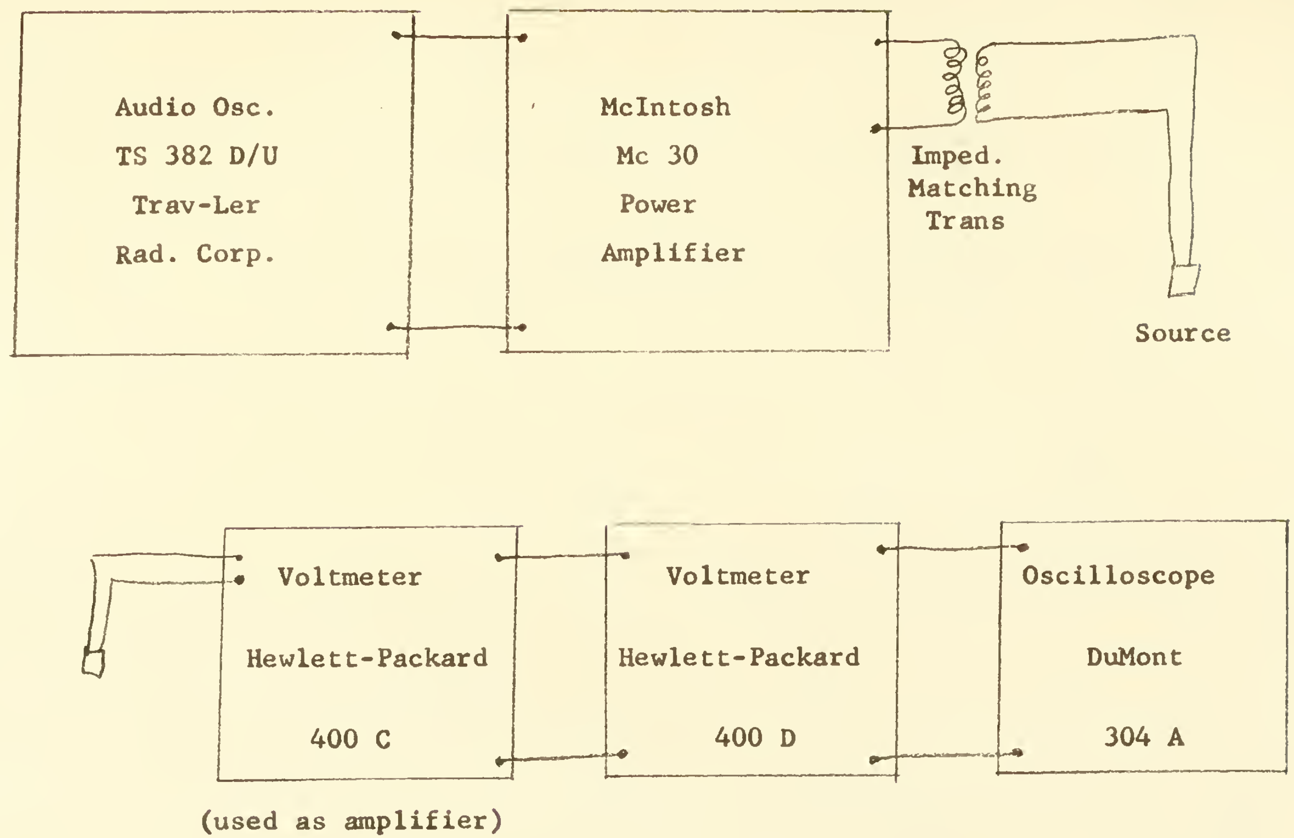
After polarization was completed, the cylinder was mounted on a plastic rod using rubber O rings for shock mounting. The plastic rod was in turn mounted in the end of a copper tube, again using O rings, for electrical shielding as well as to increase the handling and clamping ease of the source as shown in Figure 2.

The entire assembly was waterproofed with glyptol and shielded with silver paint over the dried glyptol.

The second source was made in a similar manner from a barium titanate sphere three cm. in diameter with a wall thickness of two mm. and having a mounting hole of one cm. previously drilled. Since the sphere was factory silvered, this step was unnecessary.

The sphere was polarized with 5,000 volts and the entire assembly was coated with an epoxy plastic resin spray for insulation.

Figure 1



Equipment Arrangement

Figure 2

Sound Sources

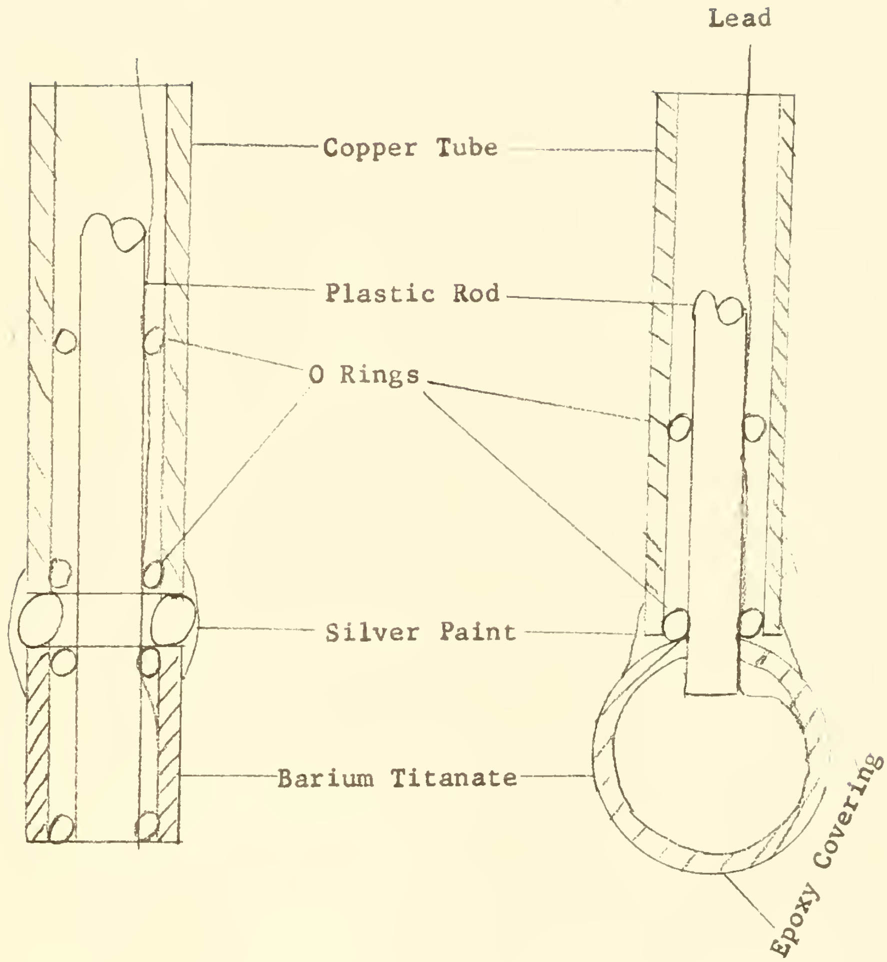
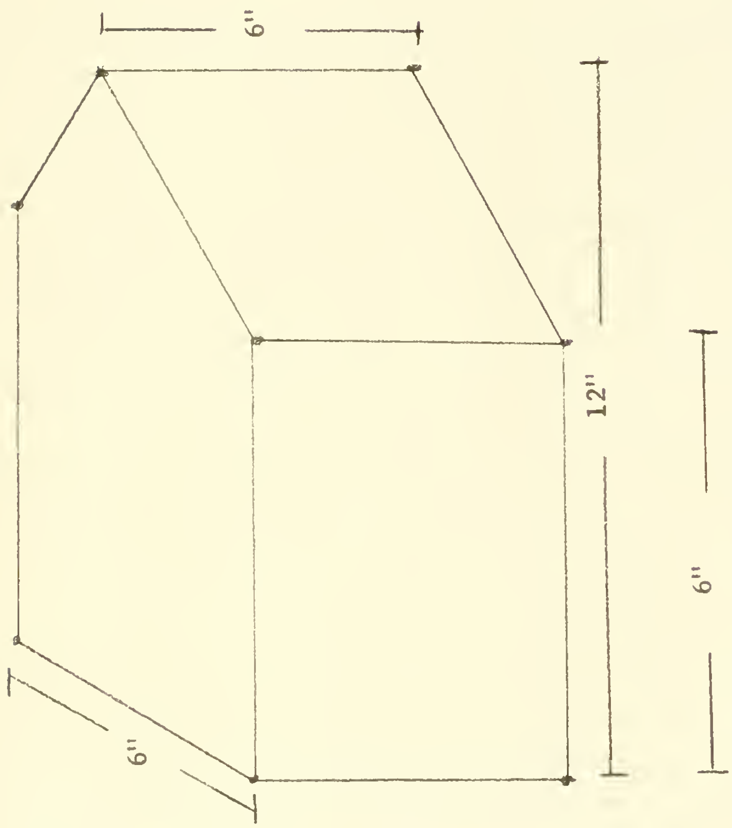
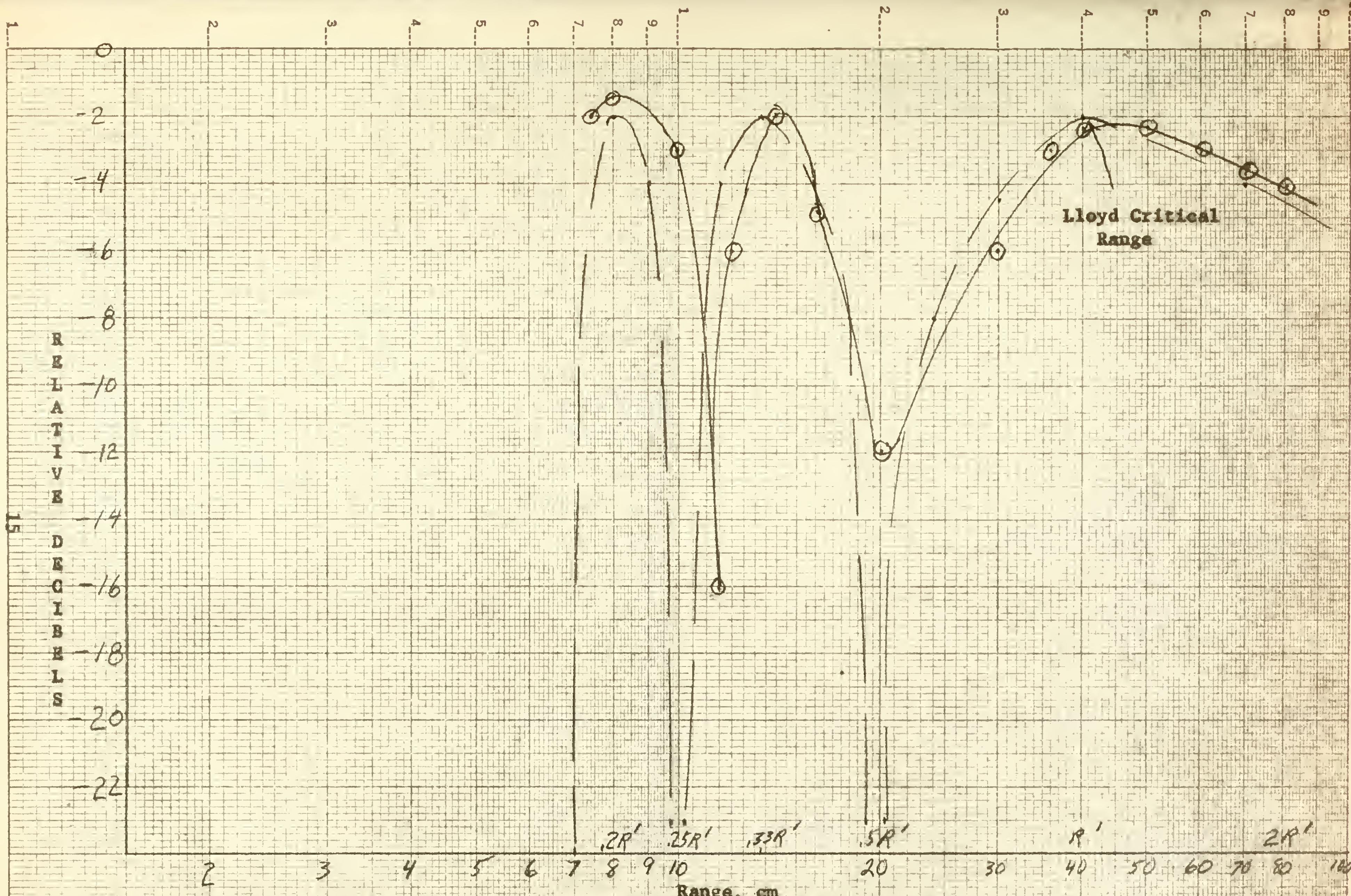


Figure 3

Insulkrete Anechoic Wedge





Plot of Sound Pressure Level Anomaly vs Range

$d = 10$ cm

$h = 10$ m

$\lambda = 10$ cm

Figure 4

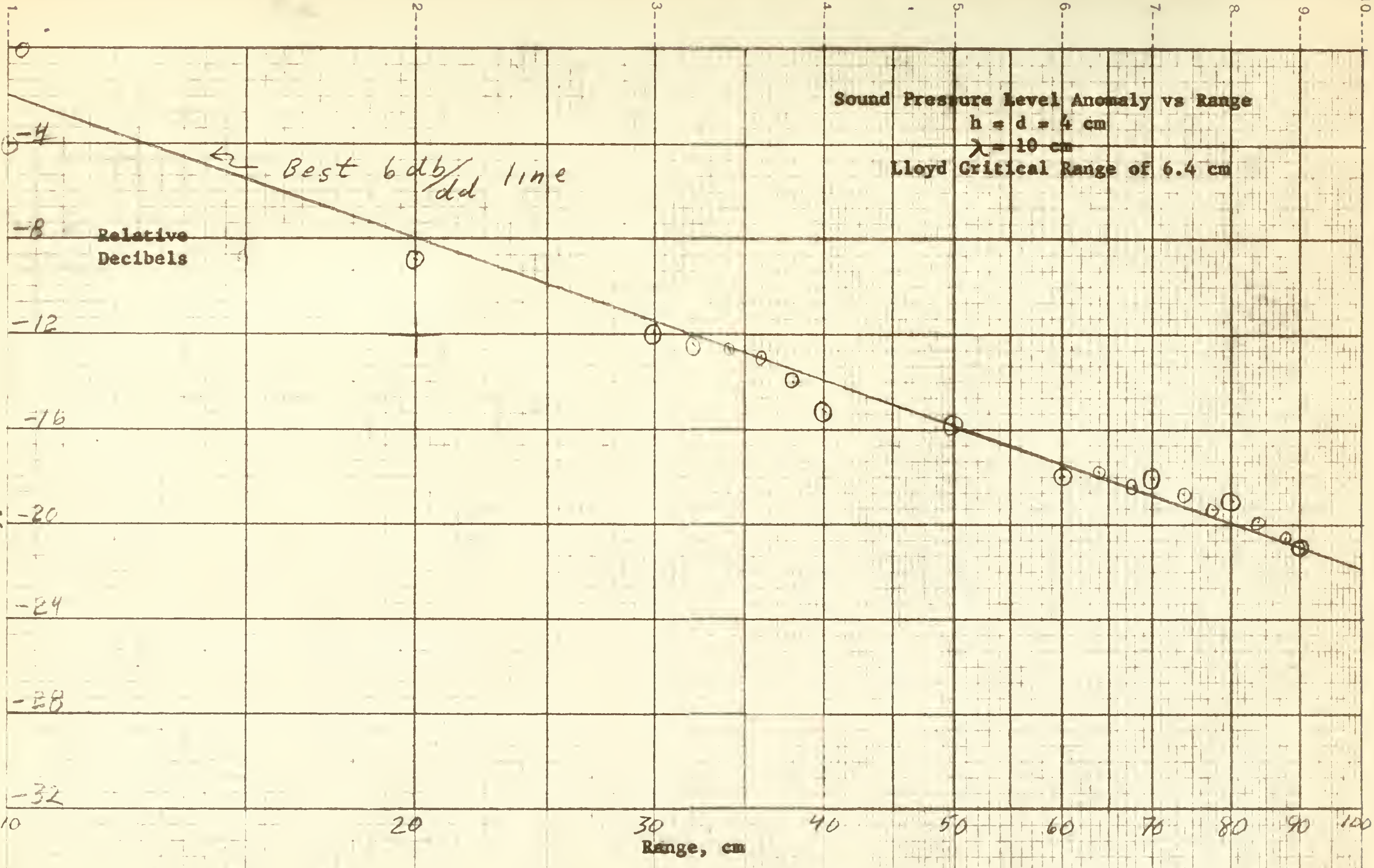

Sound Pressure Level Anomaly vs Range
h = d = 4 cm
λ = 10 cm
Lloyd Critical Range of 6.4 cm
Best 6 db/dd line
Relative Decibels
-4
-8
-12
-16
-20
-24
-28
-32
10
20
30
40
50
60
70
80
90
100
Range, cm

Figure 5